Enhanced Fluid Dynamics Modeling Capability for Endovascular Flows

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Computational fluid dynamics (CFD) is a tool to better understand the flowfields within endovascular systems. CFD can be used both to obtain a deeper insight into the causes of endovascular diseases and to guide the production of advanced interventional devices.

Using arterial geometry definitions acquired from MRI/CT scan data, simulations can be run on patient-specific cardiovascular systems. These simulations can provide clinicians and medical researchers with a wealth of information about cardiovascular flows, such as instantaneous, 3-D pressure, temperature, velocity, and velocity gradient fields that are not easily accessible with modern medical imaging techniques. With such information, doctors can track the changes in the velocity and pressure fields in a diseased area and determine how these changes contribute to the progression of a disease. This may result in not only a better understanding for the causes of cardiovascular disease, but also improved treatment techniques.

CFD can also be used as a testbed for advanced interventional devices. Before performing animal-based studies, interventional devices, such as drug-releasing stents or aneurysm-filling foams, can be simulated within endovascular flowfields to determine the device's performance capabilities. Questions as to whether or not the released drugs accumulate in the target regions, or how the aneurysm-filling foams impact the flowfield within parent arteries can be answered early in the process and properly addressed.

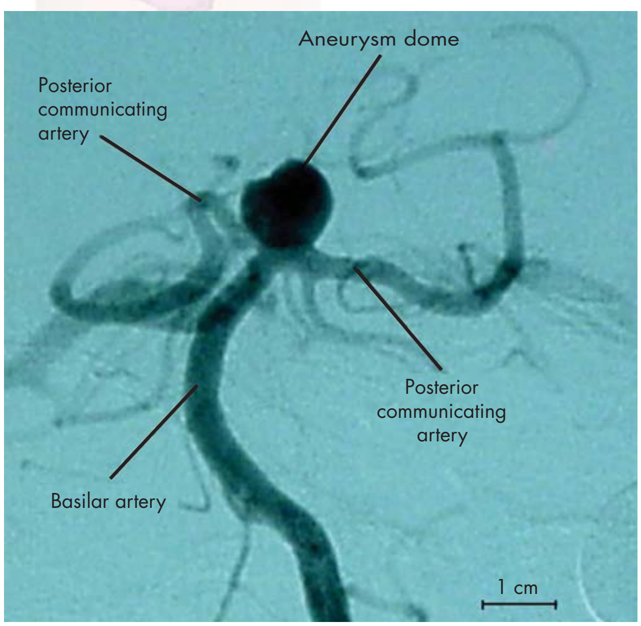

Figure 1. Angiogram of a basilar aneurysm within the brain.

Project Goals

To lay the groundwork for simulations of actual endovascular systems, the goal of this project is to perform validation simulations of the flow within a generic, terminal aneurysm on a basilar artery with a CFD software package, STAR-CD. The results of the aneurysm simulations will be compared with experimental data obtained from the Fluid Mechanics Laboratory at the University of California, Berkeley.

Relevance to LLNL Mission

The technology to accurately predict the complex, unsteady, 3-D flow through the endovascular system could have an important homeland security application in simulating the flow through the human respiratory system and determining the transport and deposition of airborne pathogens.

FY2004 Accomplishments and Results

The basilar artery is located within the brain and is a common location for aneurysm formation. An example of a terminal basilar aneurysm is shown in the angiogram in Fig. 1. The diameter of the basilar artery (3.23 mm) and the diameter of the aneurysm (11.7 mm) used in the STAR-CD simulations are average physiological values, and are shown in Fig. 2. For the simulations with STAR-CD, the boundary condition at the inlet to the basilar artery is a steady flowrate of 1.85 cm^3/s, which is approximately equal to the physiological value.

The unsteady, incompressible Navier-Stokes equations for blood flow with a constant viscosity are solved with STAR-CD using a second-order spatial discretization scheme. Information about the flowfield can be obtained by examining isosurfaces of the helicity (the inner product of the velocity and vorticity vector fields), which is a useful quantity for identifying regions of swirling flow.

Figure 3 shows isosurfaces of positive and negative helicity in the basilar bifurcation region. The distribution of these surfaces indicates that counter-rotating regions of flow form as the flow turns from the basilar artery into the posterior communicating arteries. The velocity field at a center cross-section of the aneurysm was also studied: a jet forms at the neck of the aneurysm and extends upwards, where it impinges directly upon the tip of the aneurysm. This is an important result since aneurysms often rupture at this location. The results of these simulations demonstrate that STAR-CD can be a valuable tool for obtaining detailed information about the physics of flows within endovascular systems.

Related References

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2. Stehbens, W. E., "Aneurysms and Anatomical Variation of Cerebral Arteries," *Archives of Pathology,* **75,** pp. 57-76, 1963.

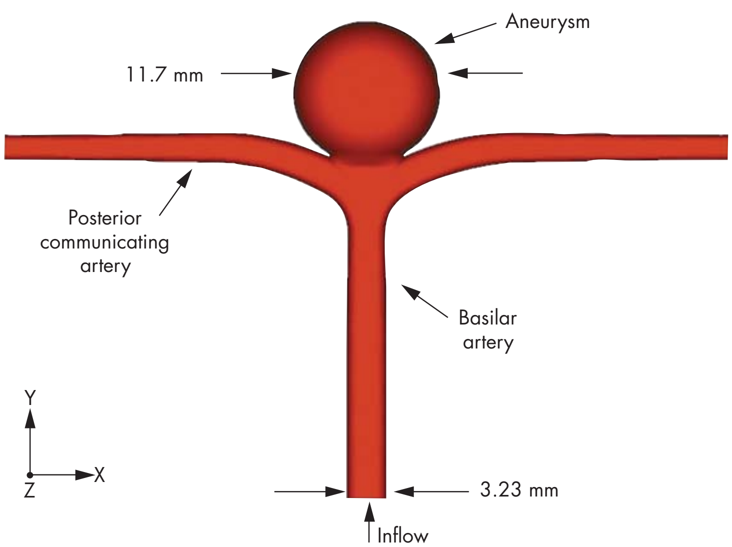

Figure 2. Computational domain for the generic basilar aneurysm simulations.

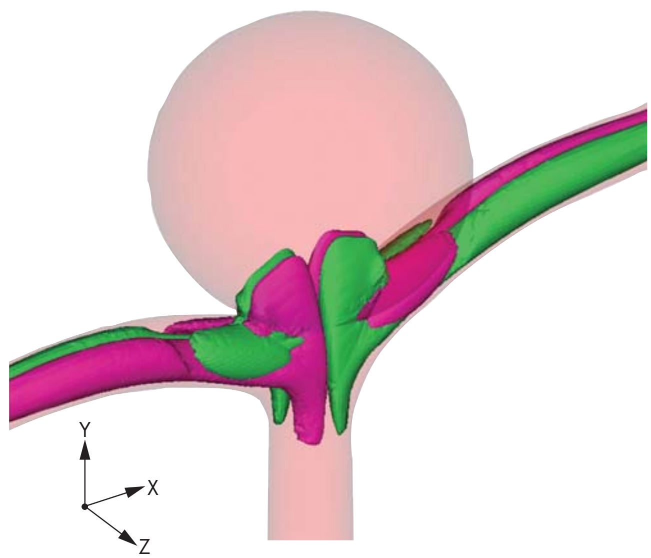

Figure 3. Positive (green) and negative (magenta) isosurfaces of helicity in the basilar bifurcation region.

Modeling Initiation in Exploding Bridgewire Detonators

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There is great interest in the dynamics of exploding bridgewire (EBW) performance and its role in the process of initiation in EBW detonators. In particular, we need to better understand the mechanism by which electrical energy stored in a fireset transforms into initiating energy within a high explosive, and how this mechanism is altered by changing materials and geometry. This project uses LLNL's magnetohydrodynamic (MHD) code CALE to model the explosion of EBWs when placed in a circuit with a fireset.

The models have been generalized from 1-D to 2-D, with the capability of including aging effects, such as the growth of intermetallic compounds.

Project Goals

The deliverables of this project include: sufficiently accurate 2-D models for pure metal EBWs surrounded by high explosive; models that predict performance of aged systems; and experiments to validate the MHD models in CALE at low energies, and the associated analyses needed for model validation. The final product is a simulation capability for EBW and slapper initiation in arbitrary configurations, an assessment tool for detonator reliability.

Relevance to LLNL Mission

This problem is of particular interest because the aging of soldered gold EBW detonators is not sufficiently understood. This simulation capability will enhance LLNL's predictive toolset, which is critical to LLNL's stockpile stewardship mission.

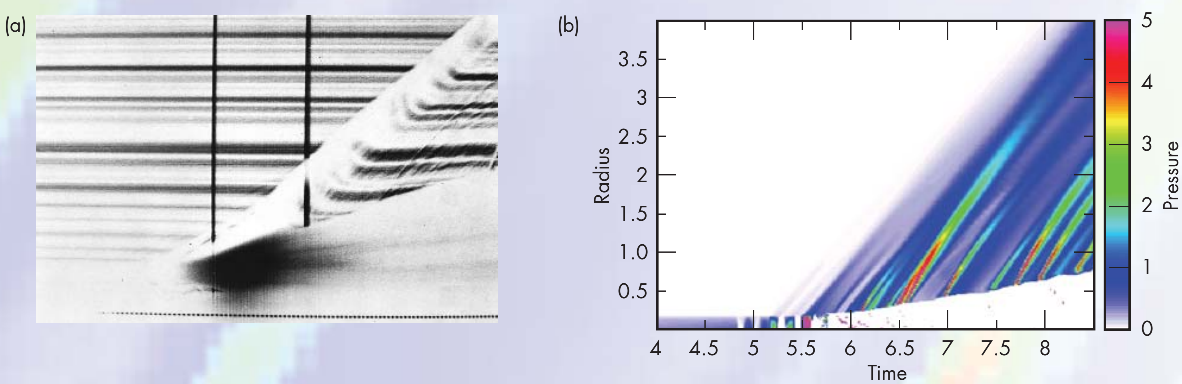

Figure 1. (a) Experimental streak image of a gold wire exploding in water. Time increases to right; the radius increases upward. Note wire expansion, followed by the material expansion (lower sloped curve) and the shock wave sent into the surrounding medium (upper sloped curve). (b) 1-D simulation of the underwater EBW experiment, presented as a streak image. Colors depict pressure levels in the wire and water.